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A COMMON COIL DESIGN FOR HIGH FIELD 2-IN-1 ACCELERATOR MAGNETS*

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Abstract

A common coil design concept for 2-in-1 superconducting accelerator magnets is presented. It practically eliminates the major problems in the ends of high field magnets built with either high temperature superconductors (HTS) or conventional superconductors. Racetrack coils, consisting of rectangular blocks built with either superconducting tapes or cables, are common to both apertures with each aperture containing one half of each coil. The ends are easy to wind with the conductors experiencing little strain. The overall magnet design, construction and tooling are also expected to be simpler than in the conventional cosine theta magnets. The concept is also suitable for superferric and combined function magnet designs. A modular design for an HTS based R&D magnet is also presented.

1 INTRODUCTION

The recent advances in high temperature superconductors have raised the expectations of using them in a high field (10T-15T) magnet design for high energy hadron colliders [1]. Conventional cosine(θ) designs may not be suitable for such magnets. In particular, problems arise in containing the large Lorentz forces and winding the coil ends since, like Nb_3Sn, HTS material exhibits poor mechanical properties. The proposed common coil design for 2-in-1 magnets overcomes these problems and offers a conductor-friendly way of making magnets. The design is well suited for coils made with tapes using the "React and Wind" technique. The conductor is wound in the easy direction and the bend radius is large. This paper is intended to present a concept rather than a detailed engineering design.

2 COMMON COIL MAGNET DESIGN

2.1 Basic Geometry

A schematic of the proposed 2-in-1 design for the main coils is shown in Fig. 1. The main coils are common to both apertures, and hence the name, 'Common Coil Magnet Design'. A set of racetrack coils, operating in series, are placed vertically on the left and right side of the two apertures producing field in opposite directions.

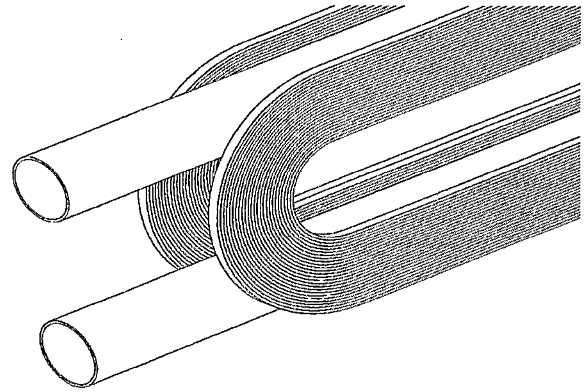

Fig. 1: The main coils in the 2-in-1 common coil design concept. The coils on the left and on the right sides of the beam tubes are common to both top and bottom apertures.

2.2 A High Field Magnet Cross-section

A preliminary magnetic design of a 50 mm aperture, 15 tesla magnet is shown in Fig. 2. The separation between the two apertures is 120 mm and the outer yoke diameter is 400 mm. The design is based on a conductor having a width of 6 mm and an overall or engineering current density (J_e) of 3 kA/mm^2. It is assumed that conductors with such performance will be available in the future. A lower current density requires a few centimeter increase in yoke diameter.

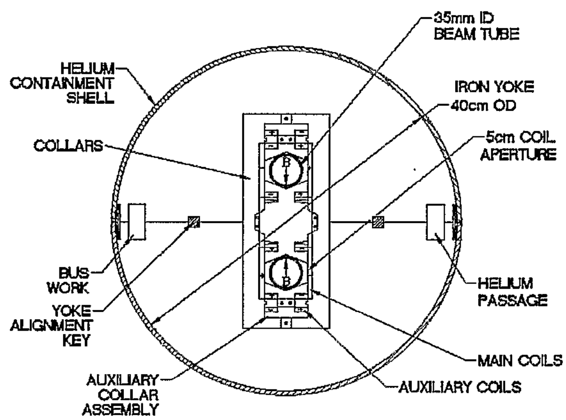

Fig. 2: A preliminary design of a 15 tesla magnet showing the main and auxiliary coils.

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In addition to main coils, there are also auxiliary coils at/near the poles. The main coils are primarily responsible for the magnitude of the field and the auxiliary coils for the field uniformity. The auxiliary coils are made with the same conductor as the main coils and are powered in series. The main coils and the auxiliary coils which are closer to the yoke midplane (lower coils of the top aperture and upper coils of the bottom aperture) are common to both apertures.

The auxiliary coils which are away from the yoke midplane (upper coils of the top aperture and lower coils of the bottom aperture) are placed in such a way that the other side of the coils returns in the same aperture. The separation between the two sides of this coil is determined by the acceptable value of the bend radius in the ends. It may be noted that though the other side of this coil makes a small negative contribution to the central field, it has a large influence in reducing the exterior field and hence reducing the yoke outer diameter. The yoke outer diameter to contain flux at 15 tesla central field is only 400 mm which is about half the size required in conventional 2-in-1 magnets. For example, the yoke diameter in 8.4 tesla, 56 mm aperture LHC 2-in-1 dipole is 550 mm. Moreover, the collar width at the midplane can be increased to contain large Lorentz forces ($\propto B^2$) without increasing the overall size, as the magnetic design does not require maximum yoke width at the midplane.

This design has an inherent up-down asymmetry which creates skew harmonics. The details of the conductor configuration are optimized to minimize the normal and skew harmonics. For the purpose of this conceptual study, the harmonics were minimized to only the 10^{-3} level at a reference radius of 10 mm. A computer model and the field lines at 15 tesla are shown in Fig. 3.

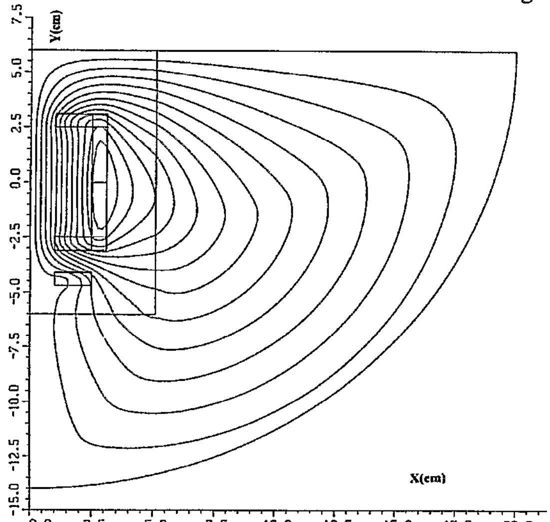

Fig. 3: The field lines at 15 tesla field in the lower-right quadrant of the proposed common coil design magnet. The coldmass is shown in ~1/3 scale.

2.3 Assembly and Mechanical Support in Magnet Body

An assembly of the main and auxiliary coils and a conceptual mechanical support structure are shown in Fig. 2. In the proposed configuration, all coils are first individually collared in a simple structure where a small pre-load is applied. The coils are then assembled in a final collared assembly and a horizontally-split yoke and shell are placed around them. In this design, the large component of the Lorentz forces is in the horizontal direction (outward) which is taken by a mechanical system consisting of stainless steel collars, yoke and the stainless steel shell. A small vertical pre-load is applied to overcome the vertical component of the Lorentz forces. The vertical component is similar to the azimuthal component of Lorentz forces in the conventional cosine theta designs, but the accumulated value is smaller here.

2.4 Magnet Ends

The ends are usually the biggest problem in the magnets, particularly those built with conductors having poor mechanical properties. The proposed design significantly reduces this problem as the tapes (or cables) are not wound in the hard direction, and furthermore, the bend radius is large. The ends can be fully supported by a simple 2-d structure. This structure can either be made of a solid piece or with laminations placed perpendicular to the body laminations of the magnet. The ends will be supported/loaded after the straight section is collared. To support from the inside, a wedge can be inserted between the body and end laminations and to load from the outside one can apply compression as is done presently in the conventional designs. The skew and normal harmonics in the ends can be minimized by optimizing the lengths and internal configuration of the various coils.

2.5 A Combined Function Magnet Design

In the proposed design the coils on the left side and right side of the aperture can have an independent geometry. Therefore, one can make a magnet where the two sides have a different number of turns, etc. In this case a combined function magnet design can be optimized where the harmonics other than dipole and quadrupole are small.

3 A HIGH FIELD R&D MAGNET DESIGN

A magnet built with the geometry used in the design described in last section but using commercially available high temperature superconductors will produce only ~2 tesla field. For near term R&D purposes, a moderate field (8T-10T at 1.8 K), 45 mm aperture, hybrid magnet using both HTS tape and normal superconducting cable, as shown in Fig. 4, is proposed. This will allow a study of the issues which are critical to making a high field magnet using high temperature superconductors, namely coil windings with HTS, mechanical support structure and the performance under the conditions that will be present in an actual magnet.

The innermost pair of coils are made with 6 mm wide HTS tapes and the outer two layers are made with 12 mm wide flat Nb-Ti cable. All six racetrack coils (three pairs) are wound on a stainless steel structure which plays an integral role in the mechanics of the magnet. Each coil and its support structure form a separate module within the magnet. A moderate amount of vertical pre-compression is applied. The coils may be potted on the horizontal plane and/or an small pre-compression may be applied to support and to ensure that no voids are left. The coil modules are installed into existing yoke laminations (with aperture modified), support shells, etc.

The modularized approach, described above, will allow an upgrade of this magnet (or replace components) when, for example, a better conductor, perhaps having a different geometry, becomes available. Various design options/principles can also be investigated without having to design and build a completely new magnet. For example, the magnet aperture and/or support structure can be changed. An adequate amount of space is left between the outermost coil and the yoke aperture to allow sufficient flexibility for such studies. For example, four HTS coils may be used to investigate a large (160 mm) single aperture quadrupole within the same overall structure.

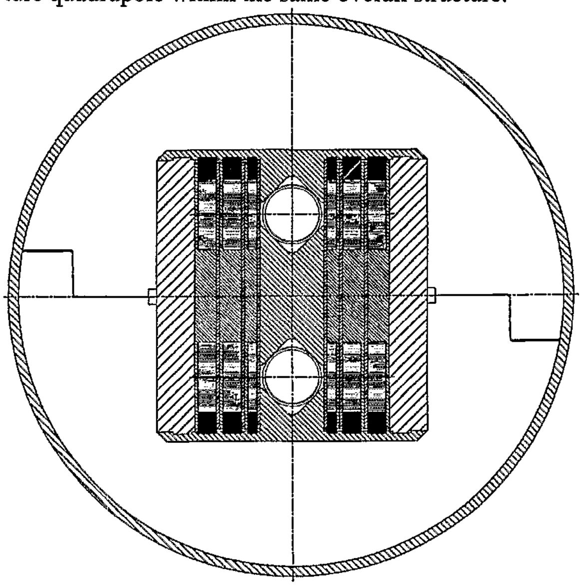

Fig. 4: A proposed R&D magnet design. The inner-most layer is made with HTS tape and the outer two with flat cables made with Nb-Ti superconductor.

4 A LOW FIELD IRON DOMINATED MAGNET

The common coil design concept offers advantages to the low field design option which are similar to those offered to high field magnets. In this case the stainless steel support structure between the two apertures will be replaced by an iron yoke to enhance the field. A magnetic design of a 2.3 tesla 2-in-1 magnet with an horizontal aperture of 45 mm and vertical aperture of 25 mm is shown in Fig. 5. The design uses a 6 mm wide tape having an overall current density of 400 A/mm^2 at 4.2 K. This is a value which, according to manufacturers [2], should be available shortly in commercially supplied high temperature superconductors. An adequate space is left for a small coil containment/support structure. The flux lines are contained in a 120 mm x 140 mm yoke.

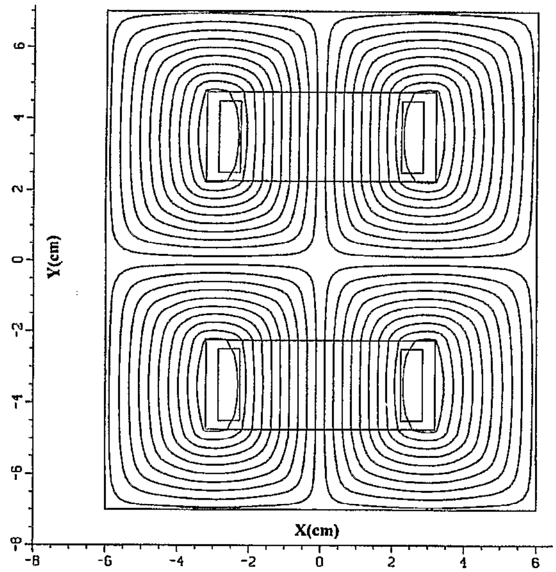

Fig. 5: A proposed low field iron dominated 45 mm x 25 mm aperture 2-in-1 magnet based on the common coil design. The coldmass is shown ~½ scale here.

5 CONCLUSIONS

The common coil magnet design concept offers a conductor friendly way of building compact high field magnets based on racetrack coils in a block configuration. High temperature superconductors have reached a stage where a serious R&D effort can be planned. The proposed modularized design approach for an R&D magnet should provide an ideal vehicle for investigating various design concepts and high temperature superconductors.

6 ACKNOWLEDGEMENTS

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[2] A. Ghosh, private communication.